LASERNET Optical Oil Debris Monitor

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Abstract: The LASERNET optical oil debris monitor has been developed for real time on line identification of fault type and severity through detection of size, shape and rate of production of failure related debris in critical applications such as engines and gearboxes of helicopters. Detection of failure related debris without sampling has required the development of a high resolution high speed imaging and processing capable of recording and analyzing images at rates up to 500 frames per second. We have designed and constructed such a system based on parallel/series CCD technology, high speed dedicated image processors and neural net classifiers. The system has been tested on the T700 engine at the helicopter power train test cell at Naval Air Warfare Center, Trenton, NJ. Qualitative performance evaluation has demonstrated the ability to detect debris in real time and to distinguish and classify air bubble patterns in varying degrees of complexity. The overall false alarm rate depends on the strategy adopted in the image processor. For a dual processor architecture the results indicate that LASERNET will be capable of operating with a false alarm (defined as an incorrect identification of a rejectable gear box) rate of less than one every 2000 operating hours.

Key words: Bearings; early warning; catastrophic failure; gears; hydraulic fluid; real-time; shape classification

Introduction: Analysis of particle morphology has been shown to provide important capability in the identification of the type and severity of mechanical faults. [1-4] Currently most morphological studies are done in laboratories and involve analysis of oil samples drawn from the equipment. Real time on line detection and analysis of failure related debris in critical applications such as engines and gearboxes of helicopters can contribute to early detection and avoidance of potentially catastrophic conditions. Operating conditions, such as oil flow rates, and the infrequent production and relatively large size of failure related debris (generally greater than 100 μm) require that effective detection of failure related debris be done in a non-sampling full flow arrangement. Detection of failure related debris without sampling has required the development of a high resolution high speed imaging and processing capable of recording and processing images at rates up to 500 frames per second.

LASERNET Description We have designed and constructed such a system based on parallel/series CCD technology, high speed dedicated image processors and neural net classifiers for fault identification. [5-9] The system has been tested on the T700 engine at the helicopter power train test cell at Naval Air Warfare Center, Trenton, NJ. A schematic of the system is shown in Fig. 1. It consists of a single mode diode laser operating at a wavelength of 830 nm, a flow adapter, a 512x512-pixel CCD imager, 512 x with a frame rate up to 1000- frames per second, and image processing electronics. The light transmitted through the viewing area of the flow adapter is imaged onto the CCD camera. Because of the speeds involved for framing and image processing, many conventional image processing approaches could not be used, and data reduction schemes had to be employed throughout the system. The uniformity of the laser illumination was

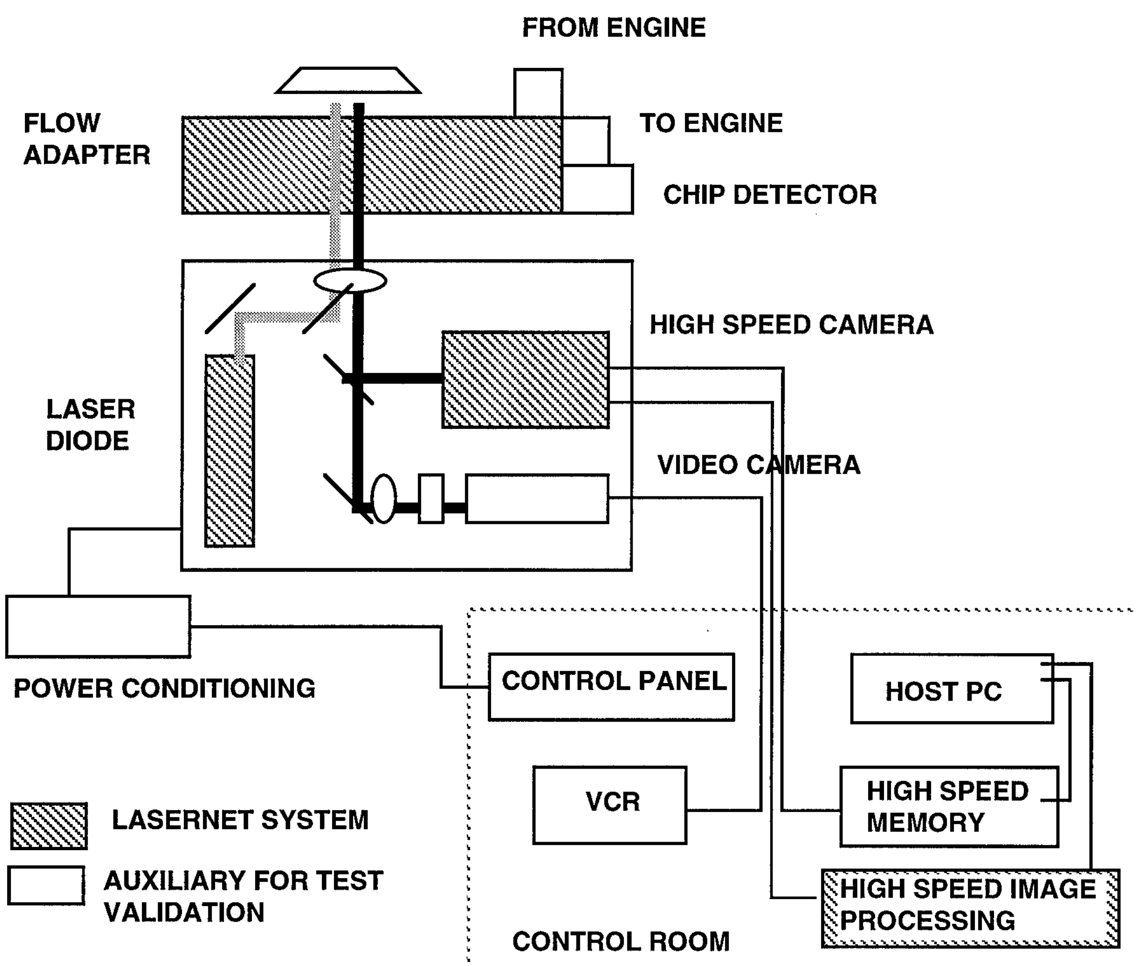

Fig. 1. Schematic diagram of the LASERNET test system for the T700 engine

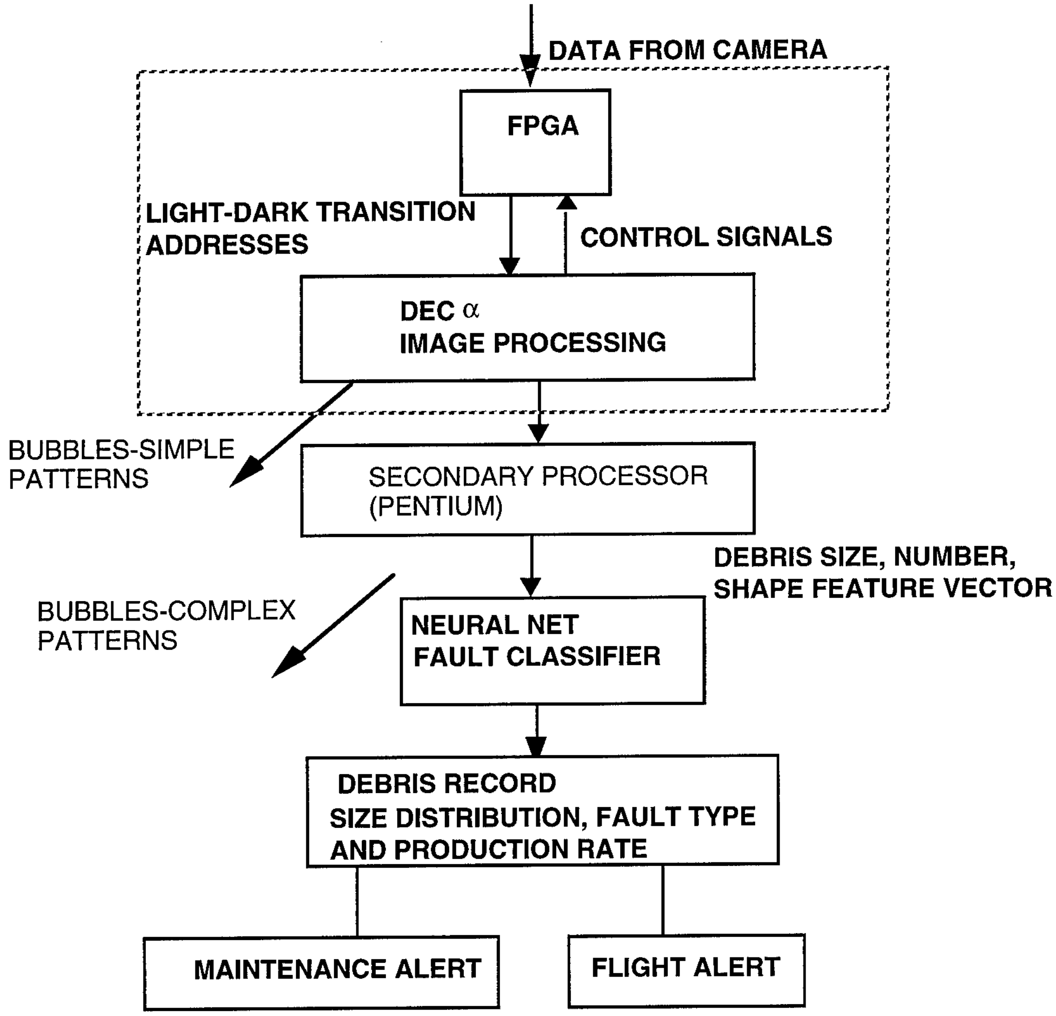

Fig. 2. Block diagram showing data flow in the image processor and fault classifier.

optimized, allowing a global threshold to be performed in the camera and one-bit image data to be transferred to the image processor.

A block diagram of the data flow in the processor is shown in Fig. 2. The data stream from the camera is held first in a full frame buffer. Pixels associated with edges of objects are identified in a field programmable gate array. The boundary pixels are assembled into individual objects in a DEC-alpha processor, and are then subjected to a series of shape identification tests. The processing strategy adopted was to identify air bubbles according to an ascending series of criteria, and to identify as debris all objects that failed the tests for bubbles. Bubbles were identified by a series of tests of increasing complexity, with objects that satisfied one level of test not being tested in subsequent steps. As a result, increasingly complex tests were applied to fewer objects, minimizing overall processing times. The tests examined objects for circularity (single bubbles), double overlapping bubbles, and multiple bubble patterns. In order to meet the speed, false alarm, and debris detection requirements a dual processor architecture was adopted. Tests for single, double and simple multiple bubble patterns were done in the serial DEC-alpha, contained in the dotted box in Fig. 2. Objects that were not discarded were passed to a second processor, which performed detailed tests based on local curvatures to identify more complex bubble patterns. The tests performed in the DEC-alpha processor reduced the computational load for the secondary processor to a level of about one object per second. The performance of the resultant system was consistent with a false alarm (defined as an incorrect identification of a rejectable gear box) rate of less than one every 2000 operating hours.

Engine Tests: The system has been tested on the T700 engine at the helicopter power train test cell at Naval Air Warfare Center, Trenton, NJ under a variety of engine operating conditions. The flow adapter was connected to the engine at the auxiliary gearbox manifold in place of the existing chip detector. The chip detector was replaced in the system immediately after the viewing area of the flow adapter, providing the opportunity for visual comparison of the two detectors. The first set of tests were directed at demonstrating an acceptably low false alarm rate along with the ability to identify failure related debris. The test on the T700 engine was chosen for the low debris generation rate of the engine, providing a platform on which the false alarm rate could be examined under a variety of conditions. The system was operated at different engine conditions including ground and flight idle and a variety of applied torques. In order to train the classifier to distinguish various air bubble patterns from debris, images of bearing debris from a bearing test stand were introduced into images obtained from the high speed imaging system.

The results of these tests are summarized in Figs. 3 and 4. In Fig. 3 the evolution of the false alarm rate, defined as an incorrect identification of a rejectable gear box, is shown over the course of the tests. As time progressed, additional tests were introduced to handle increasingly complex bubble patterns as described above, and as these tests were introduced, the false alarm rate decreased. At the end of the tests a system showing zero false alarms was operating, with the corresponding rate shown in the figure.

The corresponding particle detection efficiency is shown in Fig. 4. Here, again the detection rate increased as the processing algorithms were improved. At the end of the tests the system was close to the target for the larger particles, but somewhat below the target for smaller particles. Further improvements can be obtained with the use of higher resolution cameras (1000 x 1000) that are now available.

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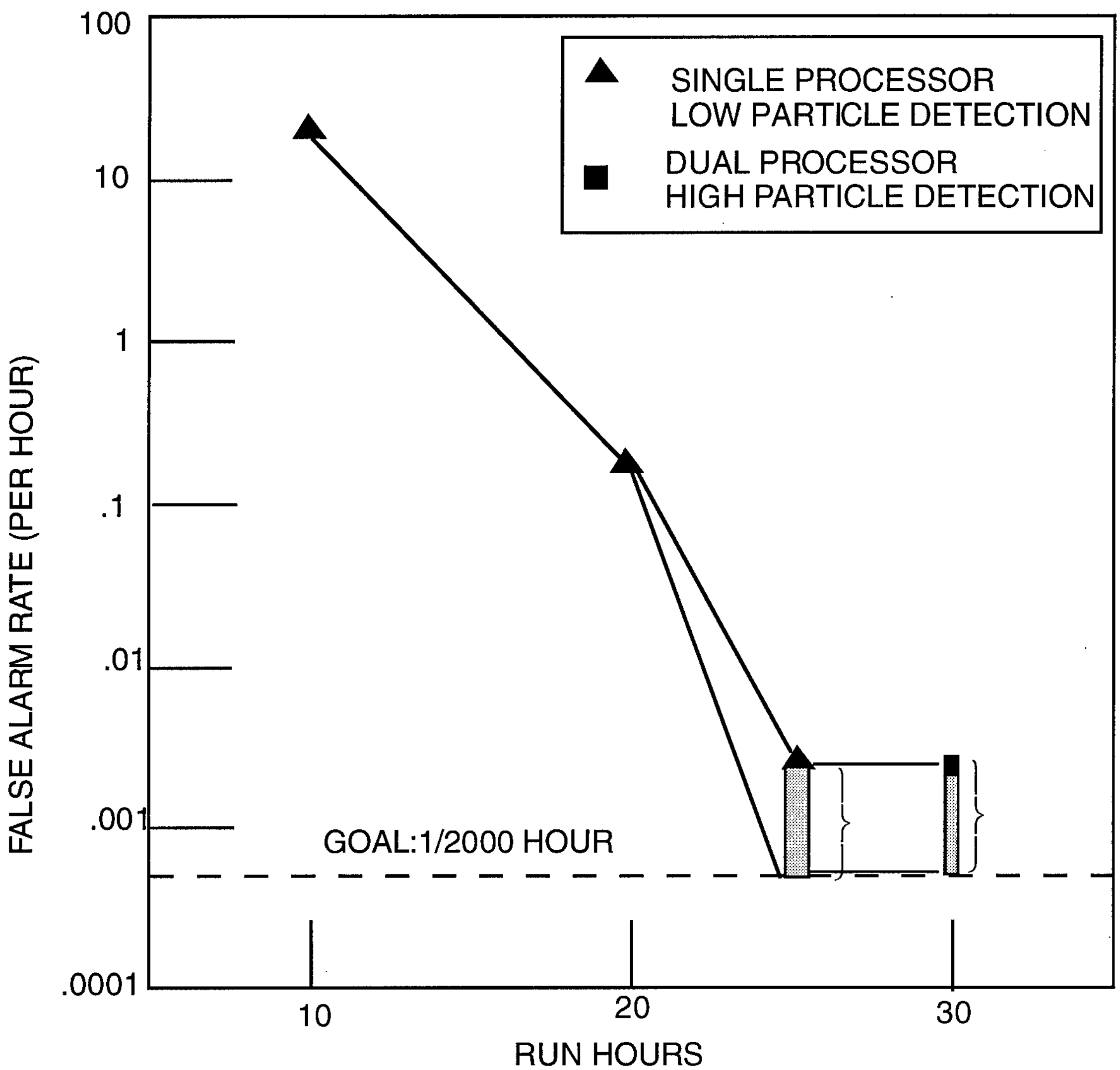

Fig. 3. False alarm rate progression for single and dual processor architecture. The brackets show the range of false alarm levels consistent with the demonstrated performance.

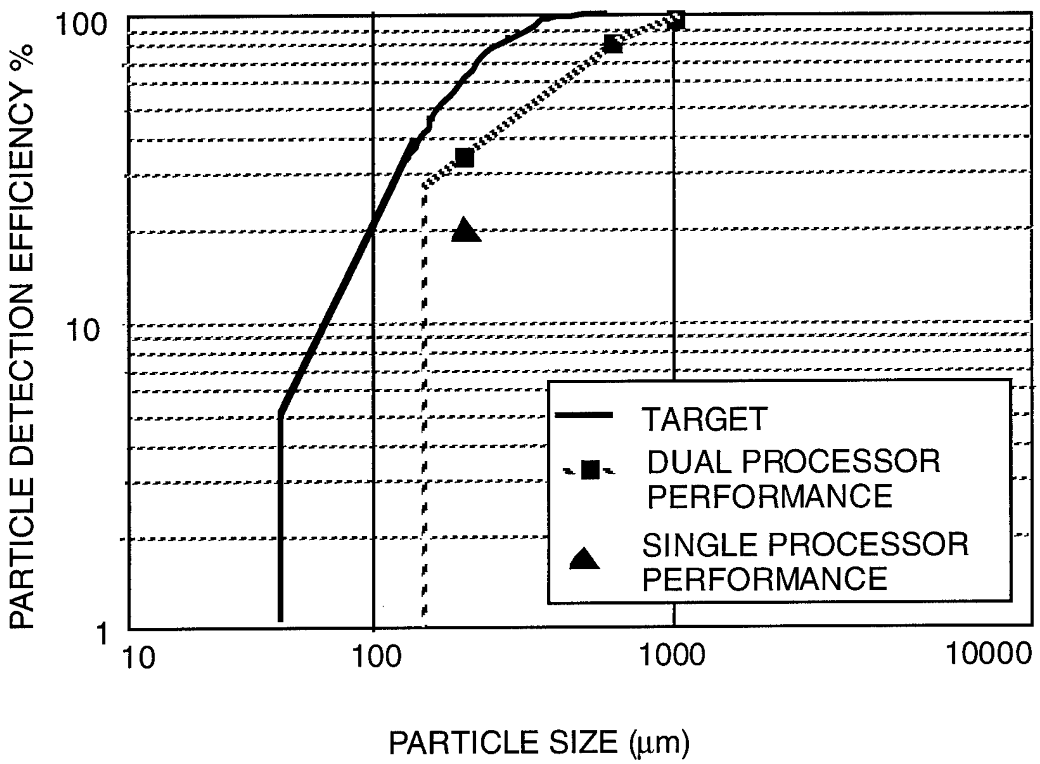

FIG. 4. Particle detection efficiency with single and dual processor architectures

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